Energy Efficient Large-Scale Building

DESIGN GUIDELINES

Ontario
Ministry of Energy
Honourable Philip Andrewes
Minister

City of Toronto
Arthur C. Eggleton
Mayor

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Zoning and Official Plan Division,
Planning and Development Department,
City of Toronto; Stephen G. McLaughlin, Commissioner

Energy
Ontario

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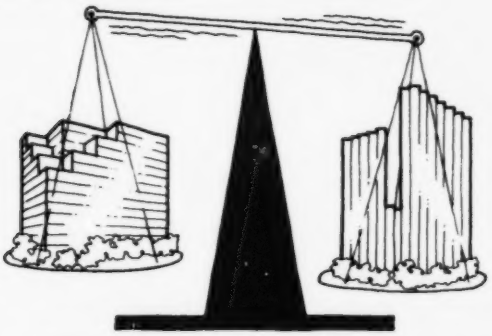
Introduction

Methods of energy conservation have become increasingly sophisticated, yet most new large buildings fail to take advantage of these advances. In many cases, energy conservation measures amount to little more than increased insulation and improved heating/air conditioning systems. *To be cost and performance effective, conservation measures should be built in during the initial design phase.*



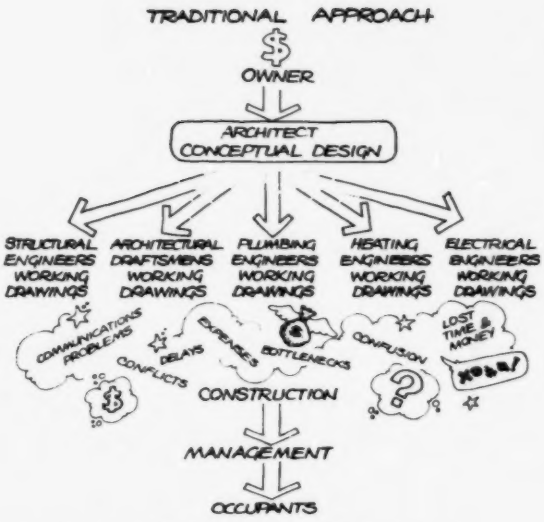
GOOD DESIGN ACHIEVES THE BEST BALANCE OF AESTHETICS AND ENERGY EFFICIENCY.

While incorporating conservation into a building design can initially prove more expensive, in the long run it enables developers, architects and contractors to save their clients money. An energy-efficient building is less expensive to operate and maintain, and can also provide a healthier, more productive working environment.

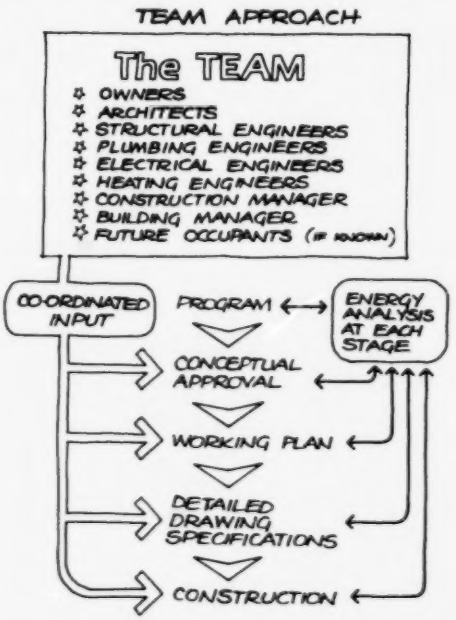
Achieving maximum energy savings for a minimal investment in time, money and effort requires a radical change in the way all parties involved in the development project tackle the problem. Energy conservation concepts must be considered before design solutions are finalized.

Traditionally, the architect sets design specifications that filter down to the builder through a series of decision-making levels, including the owner/developer, architectural, structural engineer and heating, ventilating and air-conditioning (HVAC) engineers, and building officials. These Guidelines propose a shift to a broad-based *team approach* in establishing and implementing conservation-oriented design for large-scale buildings.

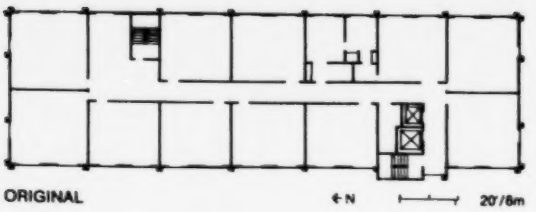
With this kind of collective planning, the architect meets with everyone involved in the project, from the developer to the end user, if possible, to discuss energy

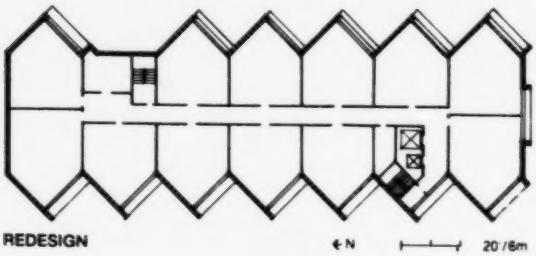


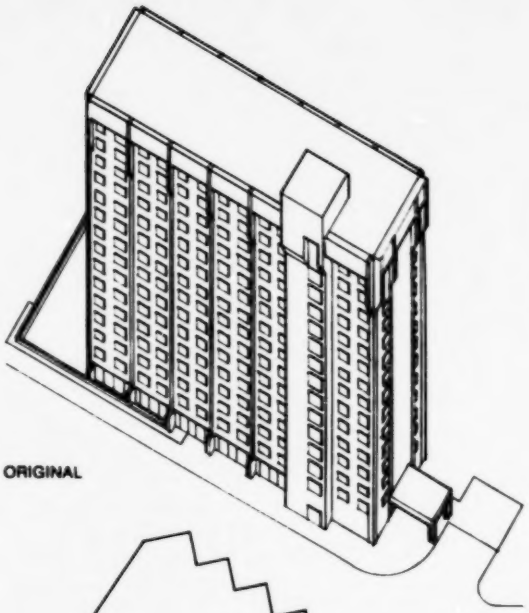
conservation goals during the initial design stage. Brainstorming sessions of this sort have proven effective in assessing the feasibility of proposed conservation measures from a variety of viewpoints.

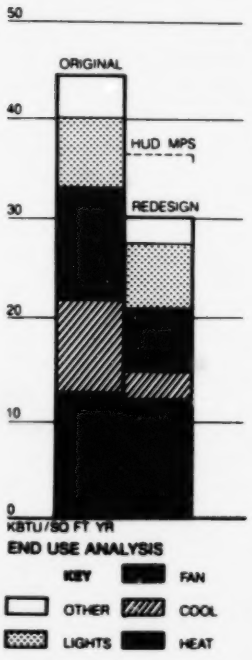


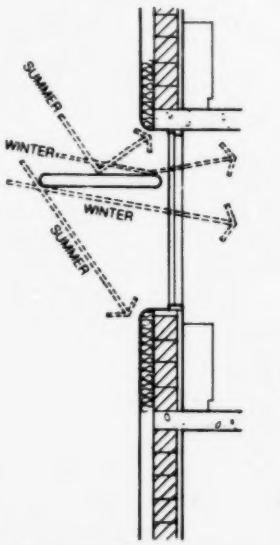
Balancing conflicting needs and aspirations very early in the planning process can prove time consuming; however, it is considerably less expensive than making major changes during construction.





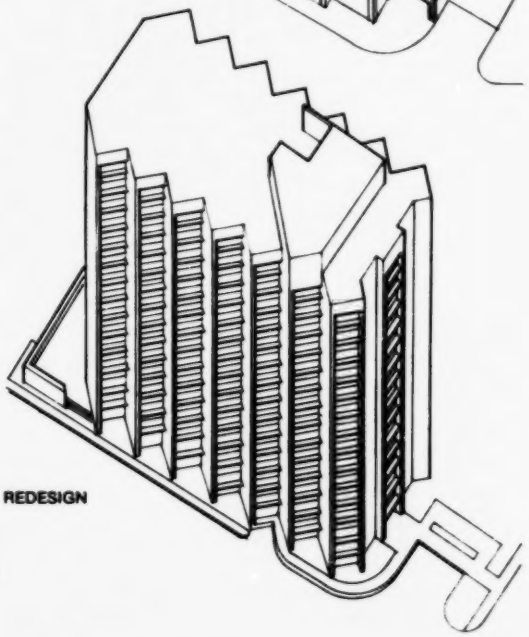






SOUTH WEST & SOUTH WALLS
SOUTH EAST – NO BLOCK, SAND OR FINS

REDESIGN: SECTION THRU MASS WALL



Example of redesign with energy in mind

This 14-storey, 128,000-sq-ft, 158-unit housing project for the elderly is in the Washington, DC, area. A severely restricted and narrow site, compounded by side-yard setback requirements, precluded any change from the original north/south orientation. The redesign solution was to "sawtooth" the building in order to reorient apartment unit glazing to the southeast and southwest. The envelope treatment differs by orientation to control the time lag of solar gains through the building structure. The southwest and south "mass" walls are 8-in. sand-filled C.M.U.'s and exterior batt insulation underneath an aluminum skin. The southeast unit walls contain no C.M.U.'s or sand. The northeast and northwest walls are windowless, of lighter construction and have 4 in. and 8 in. of batt insulation respectively. For solar control, overhangs are carefully placed in front of the unit windows to allow winter sun to enter the living space. A portion of the solar radiation is reflected from the top of the overhang to the dwelling unit's concrete ceiling, which serves as additional thermal storage. In summer, the overhangs provide shade. Building fins protect the west dwelling units from the afternoon sun while the east units have no fins to block the sun for morning heat. Other design strategies include: modular boilers and chillers for the two-pipe fan coil units; a rotary heat exchange wheel for ventilation; air conditioning; replacement of toilet exhaust fans with wind turbine ventilators; improved HVAC controls; and replacement of incandescent fixtures with fluorescent fixtures. Taken together, this combination of design strategies resulted in a 33 percent energy saving achieved at first-cost increase of about 1 percent.

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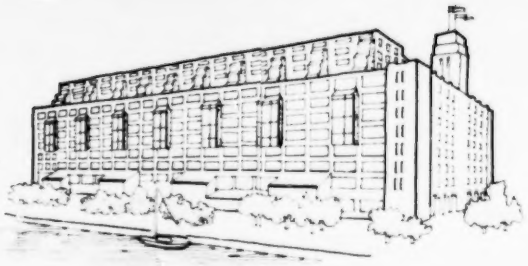
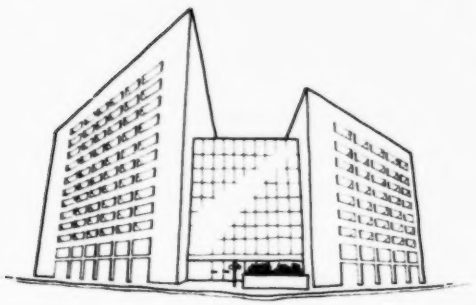
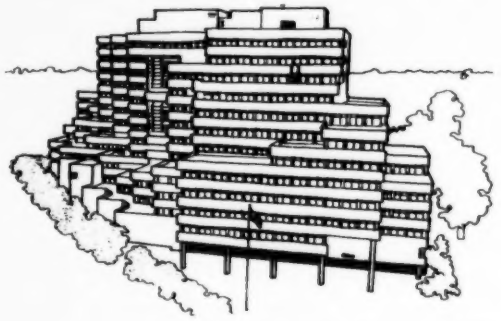
QUEEN'S QUAY TERMINAL





BELL CANADA
TRINITY SQUARE BUILDING



GOVERNMENT OFFICES

When you consider that user/property management attitudes are almost as important in determining building energy consumption as design and construction quality, the need to educate the end user takes on added significance. What better way to convey the energy conservation message than at group planning sessions where questions and concerns can be answered face-to-face?

Making all interested individuals part of the design/implementation team also helps overcome any reservations they may have concerning conservation proposals. We all feel more inclined to support a project if we believe our ideas and opinions have been taken into account. Dialogue with clients also provides architects with valuable feedback, enabling them to keep in touch with changing needs and attitudes in the marketplace.

Fluctuating oil and gas prices, construction and labour costs, demand for real estate, interest rates and government policy regarding taxes and incentives are all cited as arguments against the need to take energy conservation seriously. The fact remains: while energy-efficient buildings may cost slightly more than wasteful ones to design and build, they cost considerably less to maintain and operate.

Sparked by rapidly rising energy costs and a need to assure energy security, government and private-sector studies indicate that by installing efficient heating and air conditioning systems and adequate insulation, energy consumption in new buildings can be cut by as much as 25 percent. A further 25 percent saving can possibly be achieved by incorporating energy conservation measures into the building's architectural, structural, mechanical and electrical design. These savings can be lost, however, if they are not undertaken during the initial design stage.

A graphic example of the savings that can result from energy-conscious design took place in the U.S. when 168 commercial and residential buildings were redesigned by the buildings' original architects, following their participation in a workshop on conservation design techniques. As reported in the April 1982 issue of Progressive Architecture, "A Baseline for Energy Design", *the redesigns resulted in a 38 percent reduction in the amount of energy used by the buildings*, compared with a projected construction cost of five percent above original expenses.

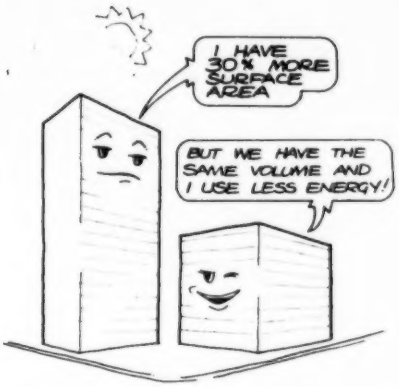
Other examples of conservation-oriented design can be found closer to home. Some noteworthy examples include Canada Square's Toronto and Calgary buildings, the Federal Government's offices at Yonge and Sheppard in North York, the Government of Ontario's facilities in Barrie, Newmarket and Oshawa, Ontario, Bell Canada's Trinity Square building in Toronto, and the Queen's Quay Terminal Warehouse mixed-use complex also in Toronto.

These Guidelines draw from a wide range of studies, professional articles and case histories to help architects, developers, engineers, property managers and end users in high density core areas to identify energy and money-saving design opportunities.

Every effort has been made to make the information as non-technical and widely accessible as possible. These Guidelines should not be looked upon as government regulations or a technical handbook; rather, they are *a state-of-the-art compendium of ideas, evaluation aids and proven design techniques*. In short, the information in this document should not be applied without first examining its appropriateness to the project at hand.

Good Things Come in Small Packages:

Energy-Efficient Building Forms



Aim:

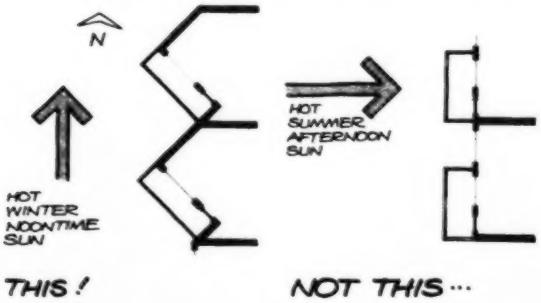
To enclose the largest volume with the least surface area, while at the same time taking full advantage of solar exposure and natural light.

A building's shape is crucial in determining its potential energy consumption. The shape influences how much of the floor area can be naturally lit, and how much solar exposure will directly contribute to heating the building. Shape and positioning in relation to prevailing winds also affect the amount of air infiltration (see section on Ventilation).

Generally speaking, the larger the building's surface area, the greater the conductive heat loss or gain, assuming the surface has the same conductive quality (insulation value). Doors and windows, however, have insulation values far below that of most roofs and walls. Consequently, window size and location should be carefully planned (see section on Glazed Areas).

Guidelines:

- Avoid unnecessarily tall, narrow, or low sprawling structures
- Avoid shapes which can expose large wall areas to prevailing winds
- Low buildings with large roof areas are also inefficient from an energy conservation viewpoint



- Whenever possible, position glazed areas to take advantage of solar energy and natural light
- Minimize floor to ceiling heights to reduce volume and improve effectiveness of artificial lighting

How and Why:

A square building has substantially less external surface (wall and roof) area than a long, narrow building. A building, 10 x 10 metres, with three floors and 300 square metres of floor area, for example, has 500 square metres of surface. By contrast, a 10 x 5 metre rectangular building with six floors and the same floor area will have 650 square metres of surface area - 30 percent more!

The taller the structure, the less protected it is from the wind. The "chimney" or "stack" effect adds to the infiltration of cold air (see section on Ventilation). A taller building also needs more sophisticated mechanical systems, including more extensive ducting and elevators. These extra requirements increase direct energy consumption and add to building volume, further increasing energy use. Recessed ceiling light fixtures also add unnecessary height to the building.

The slope or orientation of exterior walls can affect absorption levels of solar radiation. Serrated east and west walls, for example, allow for windows positioned to take advantage of natural daylight from the low-angled winter sun, while providing shade from the "high" summer sun.

In many larger buildings, solar gain from space heating is not important as excess heat is available from internal sources, such as electrical equipment, lights and even people.

Indentations in walls which provide wind breaks can also help reduce air infiltration and increase sunlight penetration.

Building Orientation:

Making Your Surroundings Work for You

Aim:

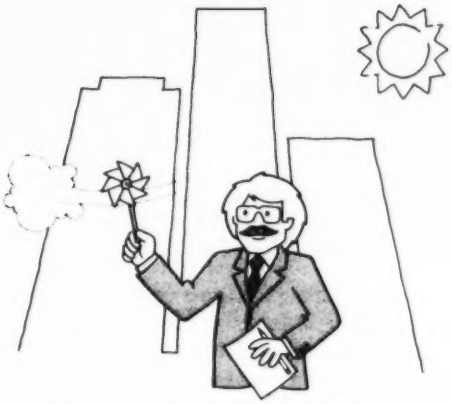
To take full advantage of natural and man-made wind breaks, solar energy and natural lighting, while minimizing the negative aspects of summer sun and winter heat loss.

How a building is positioned in relation to its immediate surroundings can have a major impact on its energy efficiency, to say nothing of its aesthetic appeal. This is particularly true for downtown locations, where neighbouring structures can greatly affect localized wind patterns and year-round exposure to sun and shade.

To avoid climate-induced problems, architects and planners should conduct ongoing site analysis and wind tunnel testing during the initial design phase, keeping in mind these rules of thumb:

Guidelines:

- Ideally a rectangular structure should be aligned on an east-west axis, avoiding, whenever possible, a north-south orientation
- Minimize wall area, particularly glazing, which faces west
- Locate the building so that the least possible amount of wall area is exposed to the prevailing wind
- Evaluate existing vegetation and site configuration to determine localized wind patterns
- Discuss possible changes to the site plan and their impact with civic planners

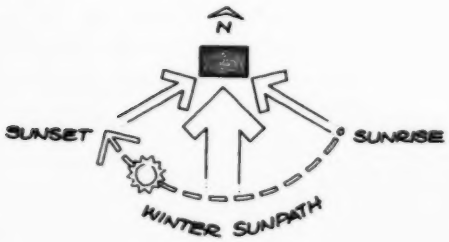


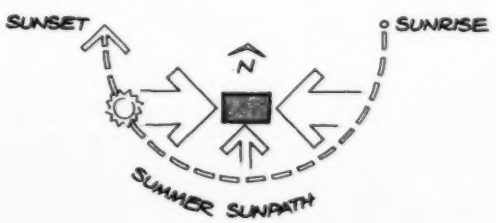
AVOID CLIMATIC PROBLEMS – CONDUCT SITE ANALYSIS AND WIND TUNNEL TESTING DURING INITIAL DESIGN PHASE.

How and Why:

Positioning a building on an east-west orientation, and providing the greatest wall and window area to the south, takes advantage of low winter sunlight while minimizing the overheating effects of the summer sun. A westerly exposure is particularly bad, because it receives direct sunlight during the hot, summer afternoons.

In Toronto, east and west exterior walls receive two and one-half times more heat from the sun in summer than in winter. By contrast, walls facing south benefit from twice the heat gain in winter as they do during the summer months!

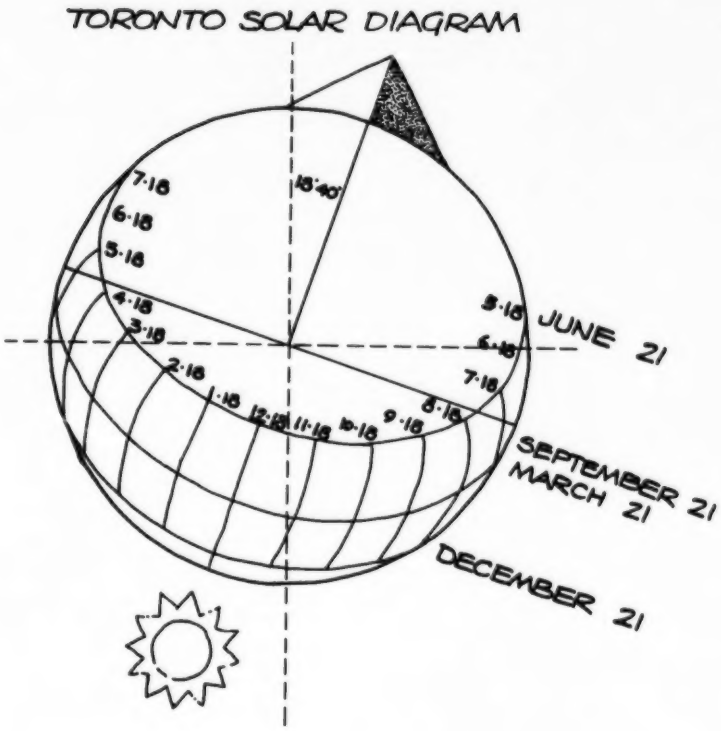


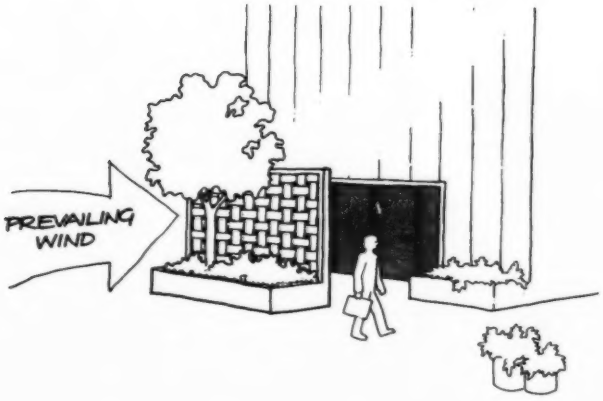


This diagram shows the path of the sun projected onto the gound plane of the City for the Summer and Winter Solstices, and the Spring and Fall Equinoxes. These projections are represented by the 3 elliptical trajectories on which are calibrated times of the day. At 12:18 p.m. EST the sun is highest in the sky. (i.e. for March 21 and December 21). Similarly, for June 21 and September 21, the sun is highest in the sky at 1:18 p.m. DST.

Furthermore, the outer circle represents the horizon; the arrowhead establishes the true North-South and East-West Axes. The diagram also shows the relationship of the rectangular Toronto street grid to the solar angles. (i.e. 18 degrees, 40 minutes, W. of N.) Consequently, a line drawn through the intersection of the North-South and East-West Axes, and a specific time of day on a particular seasonal ellipse produces the azimuth relative to the Toronto street grid.

Note: *The calibrations for times of the day are for Eastern Standard Time, and are to be used for March 21 and December 21. For June 21 and September 21, use Daylight Savings Time.*





Consideration of wind patterns prior to construction can lessen the negative effects of air infiltration and help create more efficient ventilation systems.

In the built-up environment of the city core, landscaping has only limited applications in influencing energy efficiency, such as protecting entrances and pedestrian ways.

Gimme Shelter:

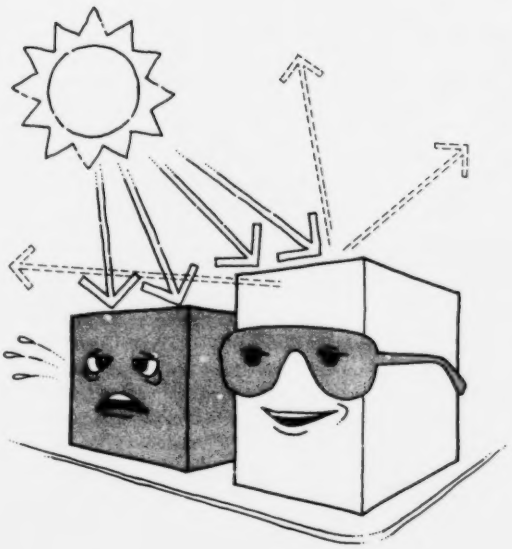
The Benefits of Protective Architectural Elements

Aim:

To shelter a building from the natural elements - sun, wind, water - and reduce heat loss and absorption by applying external, protective architectural elements and energy-efficient surface materials.

Protective architectural elements may be a fixed part of a building - an arcade, balcony, windbreak, architectural screen, or an accessory - a canopy, blind, shutter or panel. The effectiveness of any protective device is related to the quality of its construction, its heat reflective/absorptive properties, and the appropriateness of its application. Exterior protective measures are generally more efficient than interior devices.

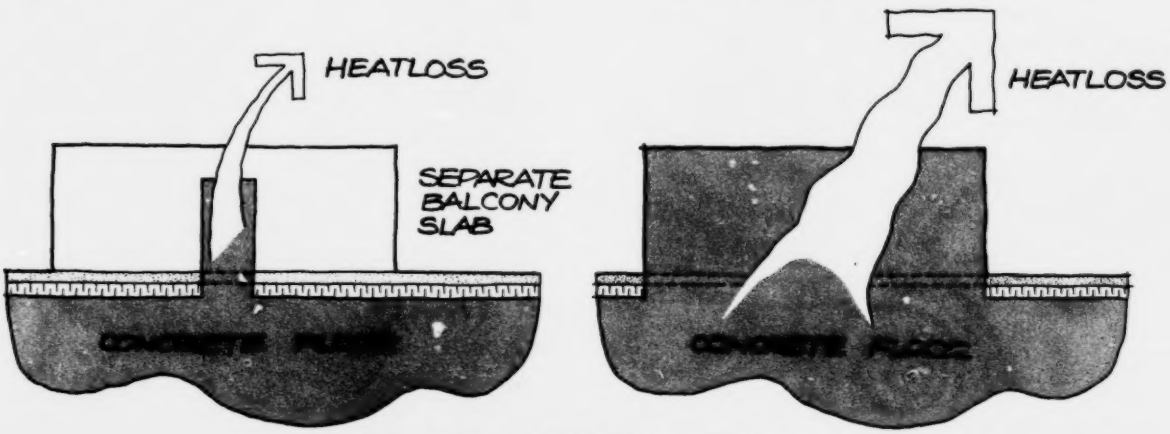
The cost effectiveness and potential visual impact of protective measures should be evaluated during the conceptual design phase, along with interior energy conservation measures. The most appropriate applications can then be determined in view of the building's intended use and locale.



LIGHT-COLOURED BUILDING MATERIALS REFLECT HEAT.

Guidelines:

- When designing protective architectural elements, don't overlook the need to react to seasonal changes
- Allow for the installation of additional protective elements, should energy performance or user demand warrant them
- Use light-coloured building materials to create a smooth, reflective exterior surface to reduce heat absorption
- Consider the use of rain screens (water-repellent outer faces) to prevent moisture seepage and allow for the use of surface insulation
- When designing fixed protective elements, such as balconies, arcades and overhangs, avoid creating thermal bridges that transfer heat gain and loss through the building's surface



AVOID HEAT TRANSFERRING THERMAL BRIDGES WHEN DESIGNING BALCONIES, ETC.

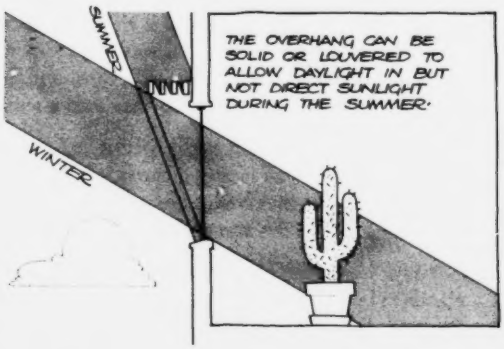
How and Why:

Horizontal overhangs, arcades and balconies can be enclosed in winter to increase solar heat gain and the insulating ability of walls and windows, while reducing air infiltration. During summer months they provide valuable shade.

Shading and lighting control

Generally, exterior elements are more effective than interior methods of providing year-round protection from the sun. However, they tend to be less adaptable to seasonal changes.

One of the simplest means of screening out undesirable light and heat, while permitting the transmission of beneficial sunlight, is the venetian blind. Enjoying a resurgence in popularity these days, horizontal and vertical venetian blinds provide flexible control of daylight, responsive to changes in outside conditions. Horizontal mini-louvre blinds not only control glare but can reflect natural light onto the ceiling, reducing dependence on artificial lighting.



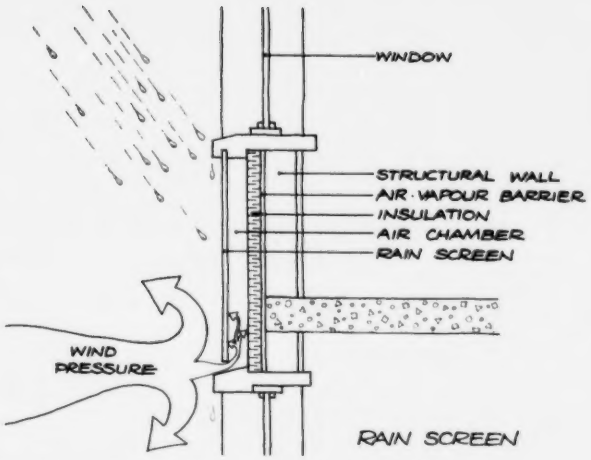
Their effectiveness can be increased by using recently developed computerized controls. As this technology becomes increasingly accessible, it will probably result in a decline in the use of reflective glass, which some people find objectionable for aesthetic reasons.

Preventing water penetration

The higher the moisture content of a wall, the poorer its insulating ability, hence the need to prevent water penetration into the wall.

Waterproof materials such as glass or metal can be used to protect walls from moisture. Traditional building materials, including concrete and brick can also be protected by constructing rain screens.

Water only penetrates a wall when three conditions exist simultaneously: water; a hole for it to pass through, and a force capable of moving the water through the hole. Rain screens are designed to eliminate the pressure difference between the outside and the inside of the wall that forces the water through the hole. This is achieved through the construction of a thin, water repellent outer face, separated from the wall by a pressure equalizing air space. This technique permits an airtight building shell, allowing the

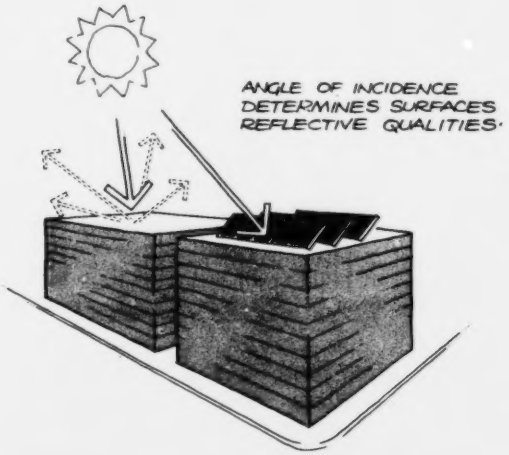


installation of insulation on the outside of the structure.

Advantages of reflective surfaces

When selecting exterior wall fabrics consider the material's ability to reduce heat and air exchange. A material's capacity to absorb heat is affected by colour and texture. Asphalt, for example, is over 20 times more absorptive than polished aluminum. Generally speaking, the darker a material's colour, the greater its ability to absorb heat.

The reflective/absorptive character of a building's surface can have a considerable impact on the cooling system required.



The reflective qualities of surfaces, such as polished metal or glass are determined by their angle of incidence. Reflective surfaces should therefore be angled to achieve an optimum level of solar absorption. Reflective glasses are *not* appropriate for most residential buildings because they keep out solar heat needed in winter.

Unless designed as part of a solar heating system, roofs shouldn't be used to absorb sunlight. In most cases, light-coloured, reflecting, well-insulated roof surfaces are the best option. Building forms and landscaping can also be used to provide shade.

Let There Be Light:

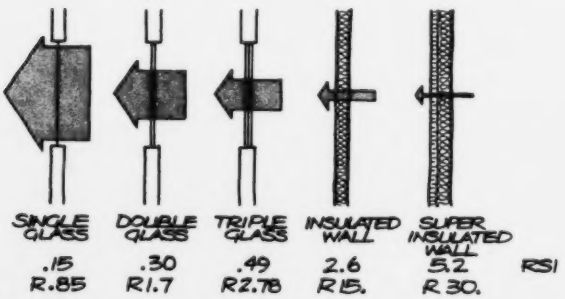
Glazed Areas - Balancing the Pros and Cons

Aim:

To take full advantage of natural light without compromising energy efficiency.

Using natural light to complement or replace artificial lighting can cut energy costs. Light transmitting areas in walls and roofs can also be used to harness solar energy. Windows and skylights make a major contribution to the aesthetic appeal of a building, and the quality of its working/living environment. That's the positive side of the story. The bad news is that glazed areas do *not* have the same insulating qualities of solid walls or roofs. (A double-glazed window has about one-tenth the insulating ability of a well-insulated wall). As well, windows can be a source of overheating. Their presence therefore, must be carefully weighed to take full advantage of their positive aspects, without compromising energy-conscious building design.

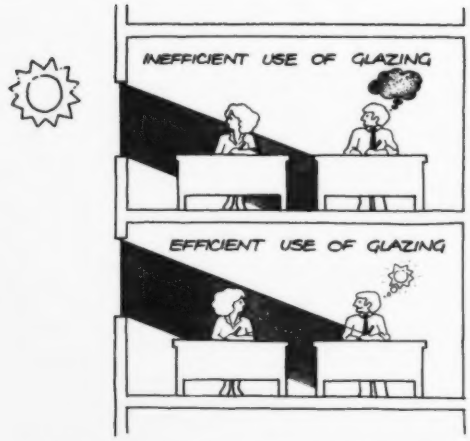
When applying the following guidelines, keep in mind that it is the *quality* of light, not the quantity of light which is most important.



Type of Glazing Treatment	*Shading Coefficient*
Single DS window glass	1.0
Inside medium venetian blind fully drawn	0.65
Plastic coating on glass lightly coloured	0.70-0.60
6 mm Bronze plate glass	0.65

Guidelines:

- Efficient placement of glazed areas transmits the *most* light with the *least* surface area
- Wherever possible, relate the size and form of glazed areas to the shape and intended use of the room in which they're located
- When selecting glazing materials, frames, etc., consider their energy conserving qualities, such as insulating value, presence of thermal breaks, and resistance to air leaks
- Place glazed areas where they'll do most good. Windows located below the level of work surfaces provide little benefit, while those placed higher up help light penetrate further into a room
- To take full advantage of the reduced dependence on artificial lighting, provide users with control devices that enable them to switch off artificial lights in the areas where natural light is adequate
- Likewise, it's necessary to provide a means of controlling the impact of natural light at different times of the day and year (see the section on Protective Architectural Elements)
- When choosing natural light control systems, look for those which help reflect light deep into the interior of a room, e.g., horizontal mini-louvre venetian blinds
- Investigate the feasibility of incorporating solar technology into the building's heating/cooling systems
- Buildings requiring cooling systems should control summer sunlight as much as possible. One of the simplest and most effective techniques is to limit the extent of glazed areas on surfaces facing east and west. The next best thing is to angle windows on east and west walls in a southerly direction. This captures beneficial winter sunlight while reducing heat gain during the summer

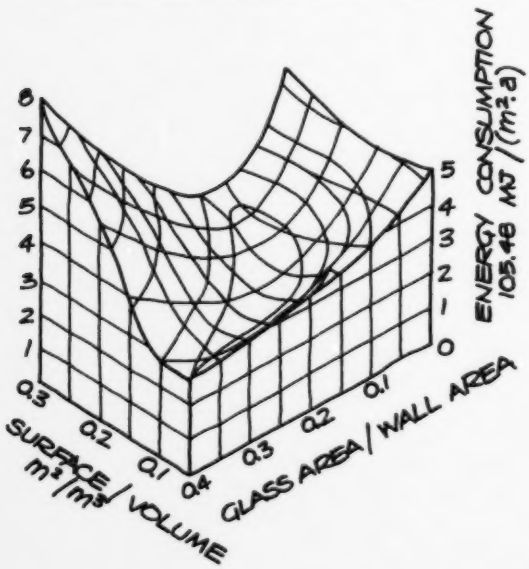


WINDOW HEIGHT AFFECTS LIGHT PENETRATION. GLAZED AREAS BELOW WORK SURFACE LEVEL ARE INEFFECTIVE.

How and Why:

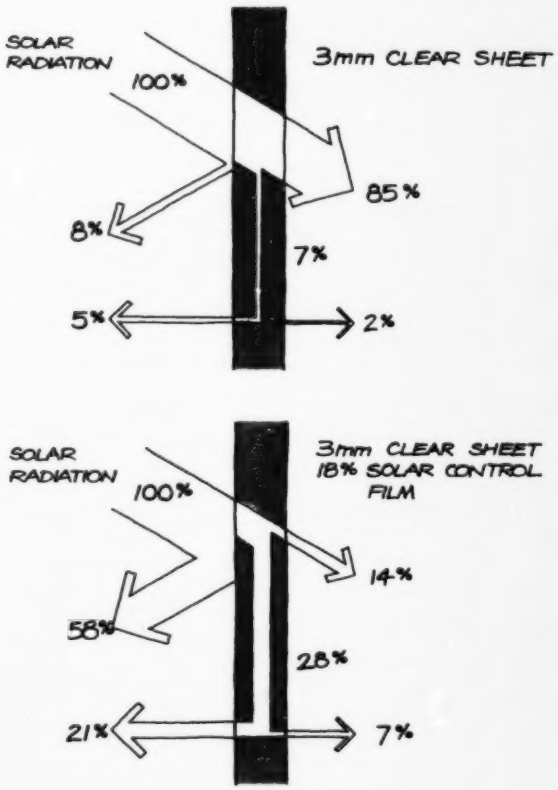
While the percentage of building surface area that is glazed can have a critical influence on a building's energy consumption, it is undesirable to regulate an optimum ratio. Each building has to be considered individually, balancing aesthetic and user demands against the poor insulation properties of glass. The Toronto Dominion towers, for example, have over a 66 percent window-to-wall ratio, while the newer Atrium on Bay, also in Toronto, has a ratio close to 25 percent. Britain's 12 percent ratio would appear to be too restrictive. For Toronto, a 25 percent window-to-wall ratio seems more appropriate for office buildings.

The challenge facing building designers is to balance the psychological needs people have for daylight - the sense of contact with the outside world that glass creates, the stimulation that sense provides (overcoming the claustrophobic feeling many of us experience in large, urban complexes) - against the economic reality that glass, while visually appealing, is, with some exceptions, not energy efficient.



3-D diagram showing the dependence of the total annual energy consumption for heating, cooling and lighting on the relative window area and on the surface to volume ratio.

COMPARISON OF SHADING COEFFICIENTS FOR SEVERAL TYPES OF GLAZING TREATMENT



Reprinted from "Energy and Buildings". See References.

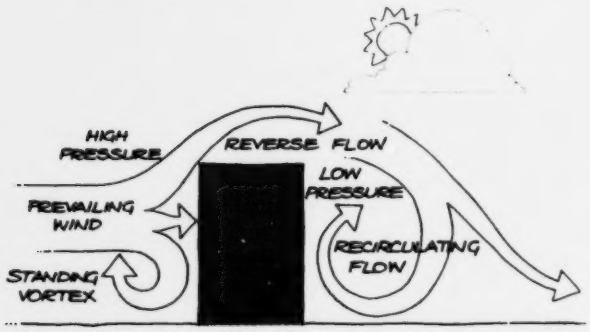
Go with the Flow:

Ventilation for Health and Comfort

Aim:

To design an energy-efficient ventilation system that satisfies comfort and health needs by taking advantage of natural rather than mechanically-induced air flow.

Ventilation is the supply or removal of air by natural or mechanical means to or from a building. In large structures, achieving this seemingly simple goal can account for 50 percent of total heating and cooling costs. Why? Because designers often rely solely on expensive, man-made ventilation systems that consume large quantities of energy and space, rather than taking advantage of natural air flow patterns that exist around many large buildings, plus recovering useful energy from exhausted air. Introducing outdoor air for cooling purposes should result in an overall decrease in energy consumption.



HOW ARCHITECTURE AFFECTS LOCALIZED WIND PATTERNS.

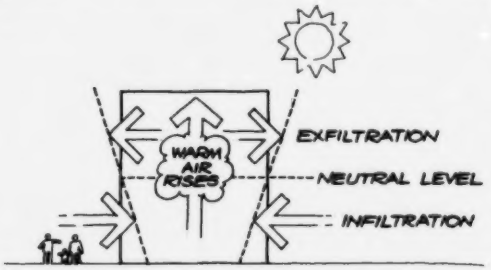
While plotting the movement of air around a structure can be difficult, (particularly in downtown locations where surrounding buildings create localized wind patterns), there are several principles of air flow which can be taken advantage of when designing ventilation systems.

General Principles of Natural Air Flow

Natural ventilation occurs when there are differences between indoor and outdoor temperatures, and when certain wind pressures exist. Air moves from warm areas to cool areas and from areas of high pressure to areas of low pressure. High pressure normally exists on the side of the building facing the prevailing wind with a lower pressure being on the opposite side. These pressure areas and air patterns can be manipulated by building form and placement of air ducts.

Another frequent air flow pattern is a ground level upwind vortex, which normally occurs at the corners of buildings. Air intakes should *not* be located at corners because of this phenomenon, which lifts dust, water and debris.

Air infiltration into taller buildings is caused mainly by the "thermal chimney" or "stack effect", (see diagram). This common form of natural air circulation



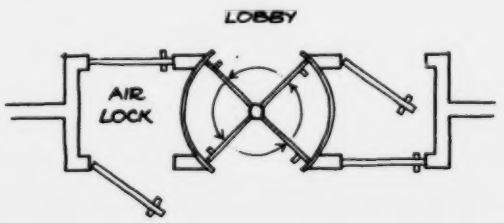
UNDESIRABLE AIR INFILTRATION CAUSED BY STACK EFFECT.

occurs when there is a difference in temperature, and corresponding difference in pressure, between the outside and inside of a building.

Uncontrolled Air Infiltration is Undesirable

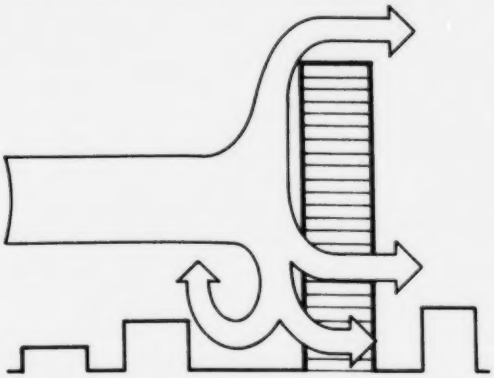
The need to bring outside air inside should not be used as a justification for the construction of a building that is not airtight. Air infiltration is *neither* an effective nor a controllable method of ventilation.

No door can be airtight, so limit their number. Airlocks such as vestibules and revolving doors help reduce air and heat exchange. Entrances should be protected from the prevailing winds by means of an architectural screen or landscaping. South-facing glazed doors, like windows, can act as solar heat collectors, reducing heat loss resulting from air exchange.

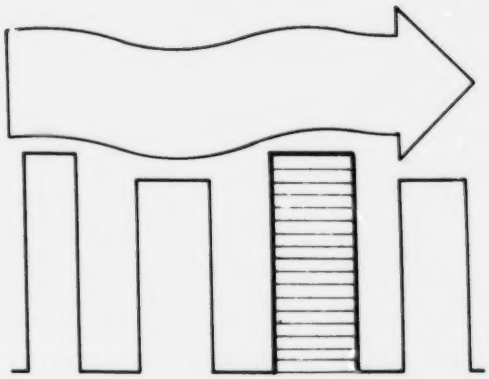


AIR LOCKS REDUCE AIR AND HEAT EXCHANGE.

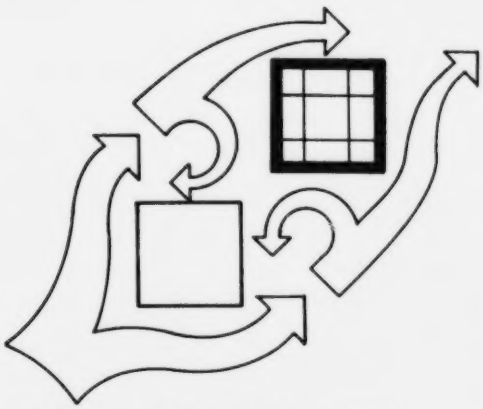
WIND EFFECTS ON TALL BUILDINGS



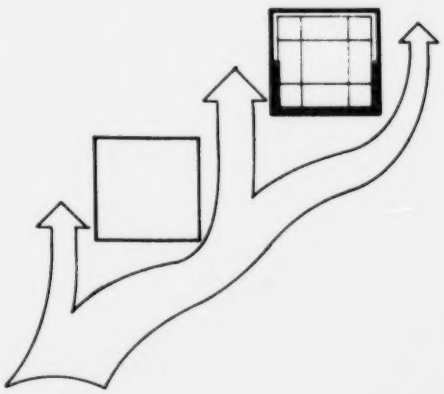
A BUILDING SIGNIFICANTLY TALLER THAN ITS SURROUNDINGS CAN EXPERIENCE HIGH WIND LOADS AND CONCENTRATE PEDESTRIAN LEVEL WINDS



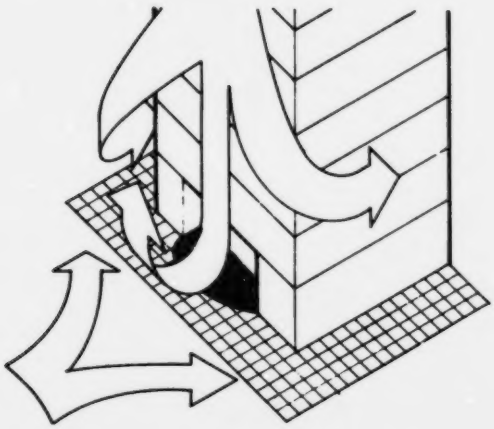
A BUILDING OF SIMILAR HEIGHT TO ITS SURROUNDINGS MAY BE PROTECTED FROM LARGE WIND LOADS AND CONCENTRATED PEDESTRIAN WINDS



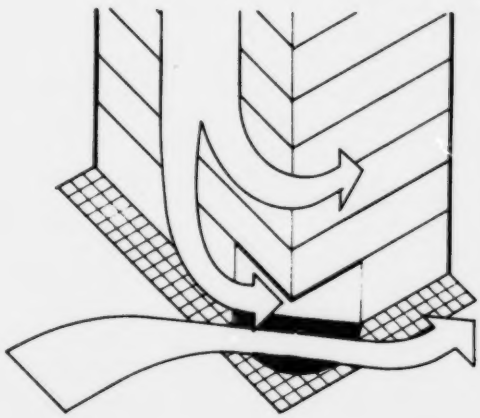
ADJACENT BUILDING PLACEMENT MAY PROTECT FROM HIGH WINDS REDUCING WIND LOADS AND PEDESTRIAN LEVEL WINDS



ADJACENT BUILDING PLACEMENT MAY DEFLECT WIND RESULTING IN HIGHER WIND LOADS AND PEDESTRIAN LEVEL WINDS



RECESSED ENTRY PROVIDES LOW WINDS AT DOOR LOCATIONS



CORNER ENTRY MAY ACCENTUATE WIND CONCENTRATION AT BUILDING CORNER

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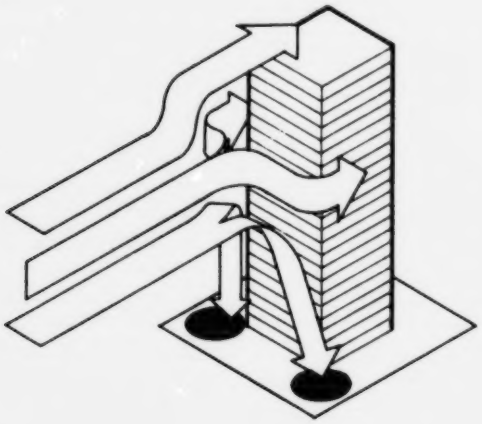
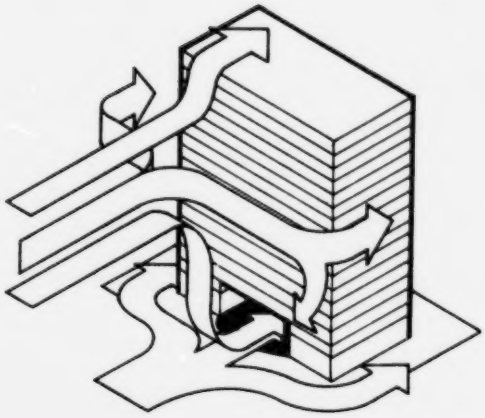
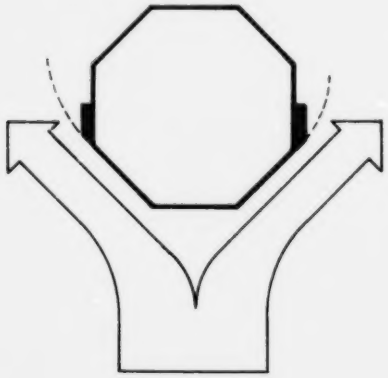
WIND EFFECTS ON TALL BUILDINGS



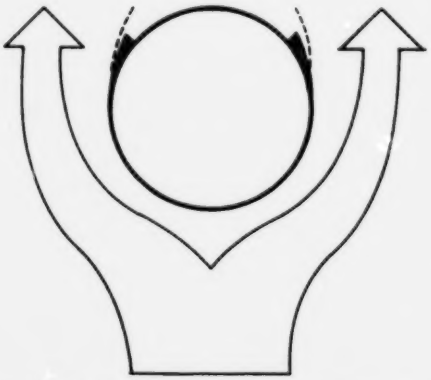
A TALL BUILDING CONCENTRATES WIND AT ITS BASE



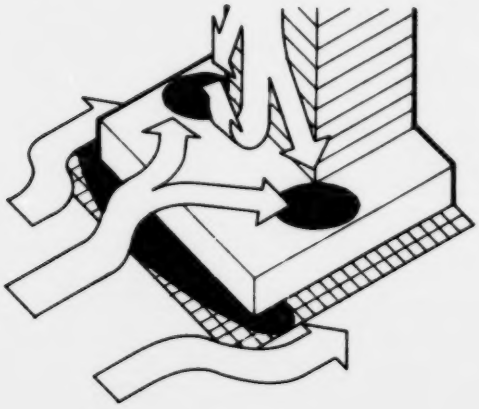
OPENINGS THROUGH A BUILDING AT THE BASE MAY INDUCE HIGH VELOCITIES IN THE OPENING



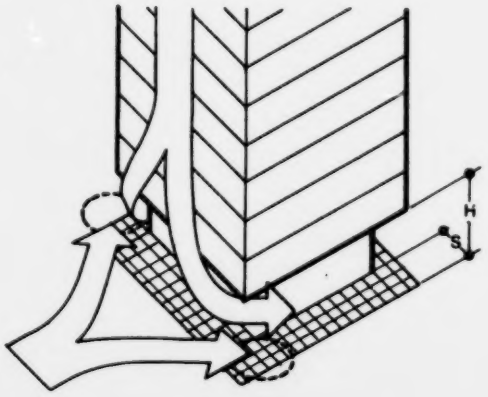
MULTI-SIDED BUILDINGS MAY NOT PERMIT FULL DEVELOPMENT OF LOCAL PRESSURES, FRAME LOADS, OR PEDESTRIAN LEVEL WINDS



CIRCULAR BUILDINGS MAY REDUCE FRAME LOADS AND PEDESTRIAN LEVEL WINDS BUT INCREASE LOCAL CLADDED LOADS AT THE POINTS WHERE THE WIND SEPARATES FROM THE BUILDING



A LOW PEDESTAL BUILDING CONCENTRATES WIND ON THE ROOF, NOT AT THE BASE



SETBACK ALL AROUND THE BUILDING MAY IMPROVE OR WORSEN WIND CONCENTRATION DEPENDING UPON S AND H

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Architects and planners should conduct detailed site analyses and wind tunnel testing using a model of the proposed building to determine natural air flows, keeping in mind the possible impact of changes to the local environment.

Allowances should be made at this initial design phase to increase the capacity of the mechanical ventilation system, should it be required. It is far more expensive to upgrade a ventilation system, once a building is complete, than to incorporate future needs into the initial design.

How and Why:

Defining a "healthy environment" isn't easy. Each of us has a different expectation for quality of air indoors. The issue of air contamination is further complicated by the fact that many of the pollutants existing in most buildings are difficult to detect. In fact, it's only recently that instruments have been developed that can measure these low levels. Still, there remains no authoritative definition of satisfactory air quality.

Probably the most significant contributor to indoor air pollution is tobacco smoke, which contains formaldehyde, nitrogen dioxide and carbon monoxide. Formaldehyde, which may cause respiratory problems, headaches, surface and eye irritation and nausea, is used as an adhesive in particle board and plywood. If not properly sealed, formaldehyde in these building materials will contaminate the air. This has led to the recent ban on ureaformaldehyde insulation. Other building materials, such as asbestos, have been linked to disease and discomfort. Varnish, wax, perfumes, disinfectants, aerosols, dust and even pet hair can all cause allergic reactions. So an effective ventilation system is essential in large buildings.

To properly understand the issue of thermal comfort, it is necessary to have knowledge of human physiological principles. It is clear that an unstable or deficient thermal environment causes behavioural and cardiovascular changes in people. This can decrease their effectiveness and have an adverse affect on their health. How a suitable environment can be effectively created is the topic of the next section.

Mechanical and Electrical Systems:

Flexibility Key to Energy Efficiency

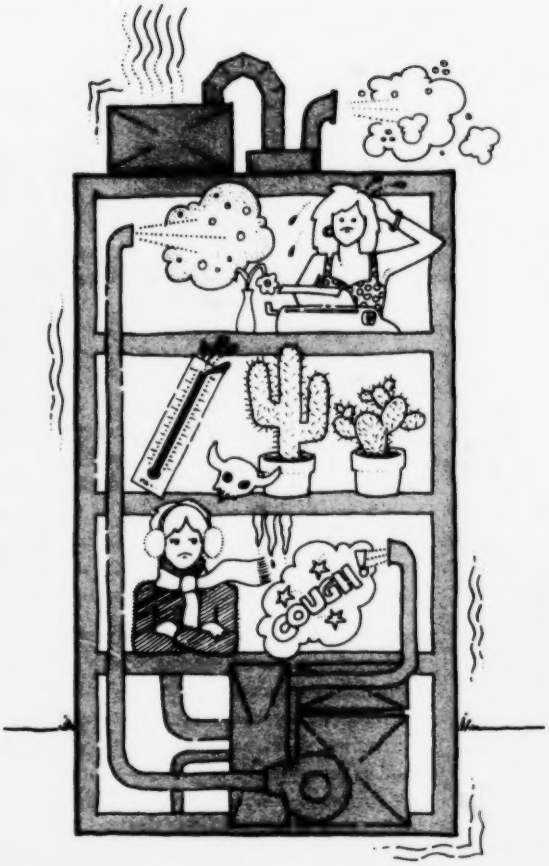
Aim:

To design a lighting and HVAC system flexible enough to meet changing requirements and supply conditions.

Electric lighting, heating, ventilation and air-conditioning (HVAC) systems account for the bulk of energy consumed by most large-scale buildings. The more adaptable and optimally sized these systems are, the less costly they are to install, maintain and operate.

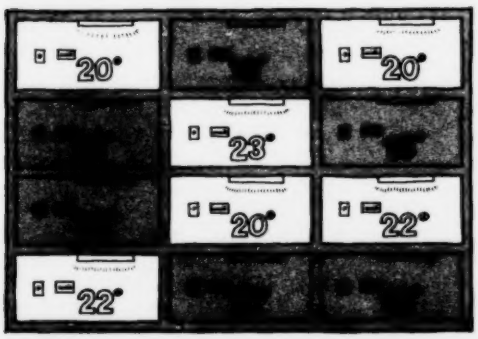
Guidelines:

- During the initial planning stage, integrate the electrical and mechanical systems into the overall design scheme of the building
- Take into account the substantial amount of energy produced by occupants and equipment
- Use zone systems with localized controls rather than a centralized HVAC system
- Avoid oversized equipment, with its unnecessarily large capacity
- Aim for quality rather than quantity in lighting, heating, cooling and ventilation systems
- Establish comfort zones which correspond to user requirements, with independent controls where necessary, rather than creating a uniform comfort zone including unused areas
- Evaluate alternative energy sources, such as steam (district heating) and solar power, to determine feasibility and cost effectiveness
- Store and recover energy waste whenever practical



DESIGN HVAC SYSTEM TO ALLOW OCCUPANTS TO SET COMFORT LEVELS.

THIS!



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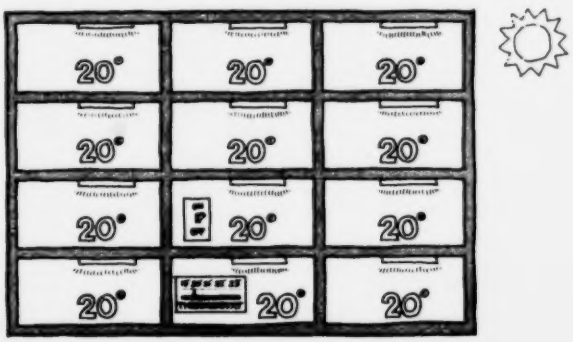


CREATE A ZONE SYSTEM WITH INDIVIDUAL CONTROLS RATHER THAN CENTRALIZED HVAC.

TASK LIGHTING

How and Why:

Most HVAC systems are sized to operate under conditions which occur less than five percent of the time. In other words, the majority of HVAC systems operate less efficiently 95 percent of the time. Frequently, systems are 10 to 20 percent oversized. These underutilized systems cycle on and off more often than a system which works closer to full capacity. This not only wastes energy, but also creates a less comfortable, more changeable environment. Larger systems also require more space for machinery and ducts, which in turn leads to higher rates of energy consumption.

Often the large amount of energy created by people and equipment, i.e. lighting, computers, etc., is not properly considered when designing the system.

Oversized HVAC systems are often installed to meet the 10-25 percent load demand required to create the desired environment quickly from the morning start-up, after the system has been turned off at night. It's often more efficient to operate the system on a continuous basis (with reduced levels at off-peak periods) rather than shutting down equipment which tends to increase wear and tear and reduce comfort levels.

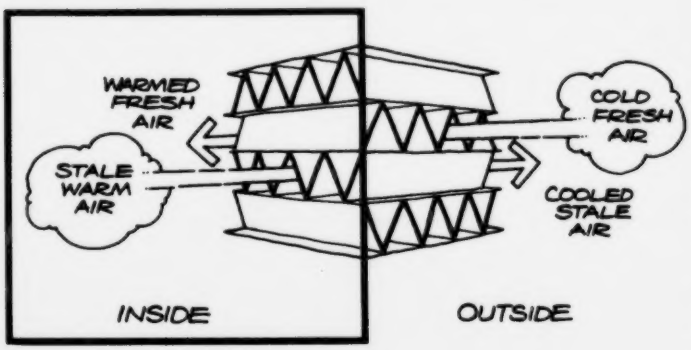
Electric lighting is often over-supplied. Lighting is usually designed around the provision of high-intensity recessed ceiling fixtures throughout a building. If a ceiling plenum space does not exist for other reasons (HVAC ducts for example), the creation of a dropped ceiling solely for the purpose of incorporating recessed lighting may add five percent to building volume. Instead of uniform light levels throughout, task lighting should be used, where light intensity is related to the specific needs of the user. Energy and cost considerations aside, task lighting can improve worker productivity. It can even help alleviate eye-strain, as in the case of video display terminal operators. Again, the proper placement and type of fixtures can improve the quality of light while increasing energy efficiency.

Further savings can be realized by controlling light levels in unused or under-utilized areas. Lighting controls should also be able to take advantage of natural light through the provision of separate switches for lights near the glazed building perimeter.

Flexibility in the design of electrical and HVAC systems is necessary to meet future requirements and to accommodate the needs of different areas within a building. If only one area of a building is used at night, for example, it is wasteful to light, ventilate, heat or cool the entire building to maximum levels. If the requirements of areas or users vary substantially, a number of individually controlled HVAC units may be more efficient than one central system.

Making use of waste energy can provide substantial energy savings. Perhaps the most significant form of heat recovery occurs when heated exhaust air is passed through ventilation ducts to pre-heat incoming fresh air. Process heat can also be recovered from equipment. Where reclaimed heat cannot be used immediately, storage facilities may be needed. When evaluating energy storage systems, make sure energy savings outweigh the drawbacks of increased building volume and extra construction costs.

The choice of energy supply is crucial. Price, availability and future supply should be taken into account when selecting energy sources. If steam is available from district heating systems, as is the case in downtown Toronto, or from industrial plants, this may eliminate the need for large, costly boiler rooms.



HEAT EXCHANGER PRINCIPLE AT WORK.

From the Inside Out:

Energy-Conscious Interior Design

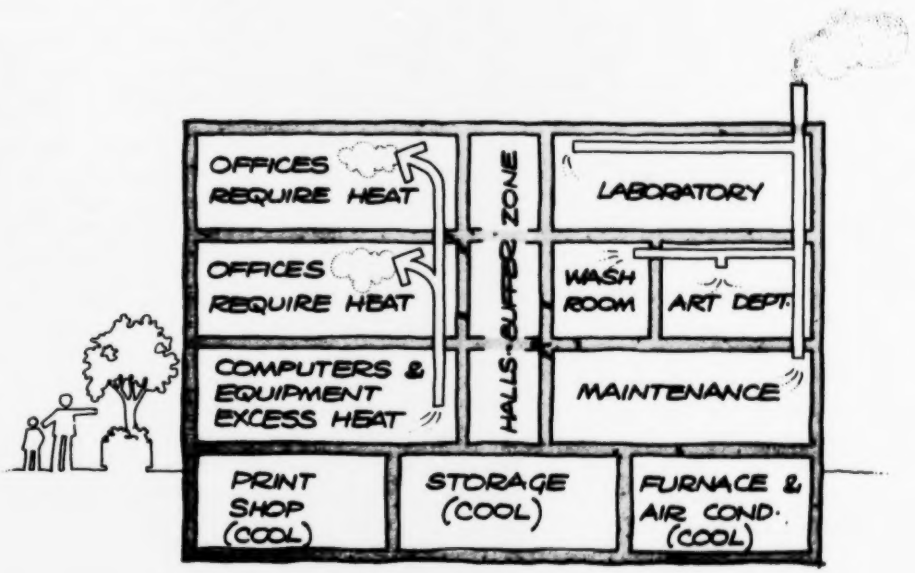
Aim:

Creation of an interior layout geared to minimize energy consumption and accommodate user needs, that's flexible enough to respond effectively to future demands.

To optimize energy usage, it's important to analyze present, and if possible, future energy needs of end users in all parts of a building, tailoring interior plans and mechanical heating, lighting, cooling, ventilation systems to meet these perceived needs.

Guidelines:

- Areas with similar energy requirements or interdependent functions should be grouped together
- Heavy traffic areas should be located near entrances
- Areas requiring lower levels of environmental comfort, such as entrances, shipping/receiving areas, storage space, should be used as buffer zones to protect comfort-sensitive sections
- Areas producing surplus energy should be located adjacent to sections requiring supplementary energy
- Effective environmental controls should be provided to reduce or close down power to low-use areas
- Flexible environmental controls should have built-in provisions for future energy demands
- When designing energy systems, allow for changes in layout so that future energy requirements can be met in an efficient manner
- An open floor plan is generally more energy-efficient than separate rooms. Partitions reduce the effectiveness of heating, cooling, ventilation, natural and artificial light
- In areas where partitions are required, it is essential that heating, cooling and ventilation systems be designed to accommodate these room dividers. Providing desirable environmental conditions will be more difficult and costly if allowances for partitions are not made in the initial design



DIFFERENT AREAS AND USES WITHIN A STRUCTURE DEMAND MORE OR LESS ENERGY. REMEMBER TO GROUP TOGETHER AREAS WITH SIMILAR ENERGY REQUIREMENTS OR INTERDEPENDENT FUNCTIONS.

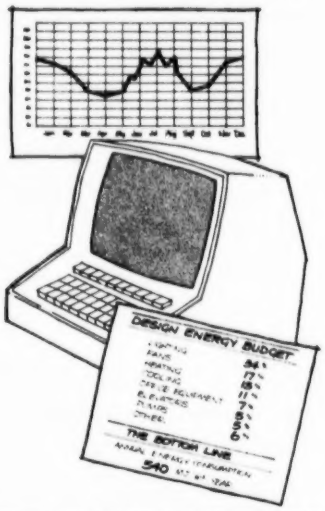
The Bottom Line:

How to Evaluate Energy-Related Design

Aim:

To gauge the impact of design decisions on the energy performance of a building.

Computer-enhanced energy analysis can be a valuable design tool for testing the effectiveness of various architectural solutions and design possibilities. It can also provide a yardstick for comparing the relative energy performance of different buildings.



COMPUTER ENHANCED ENERGY ANALYSIS CAN BE A VALUABLE DESIGN TOOL.

Guidelines:

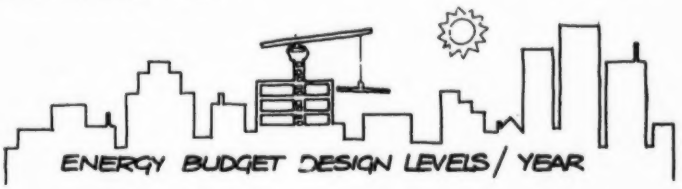
- Become familiar with sophisticated computer programs which offer new ways of determining the most efficient and appropriate environmental control systems
- Use this new technology to resolve the dilemma of energy efficiency versus cost effectiveness, as it pertains to specific design alternatives. Computers can also be used when performing Sensitivity Analysis and Life-Cycle Costing for important design decisions and equipment choices
- Use computer programs to predict the overall energy consumption of a proposed building design, for the purpose of evaluating its performance in relation to other compatible buildings

How and Why:

The task of defining energy efficiency in real terms is complex and difficult, as demonstrated by the U.S. attempt to develop Building Energy Performance Standards for new commercial buildings.

The intended standards, while unlikely to become binding, do provide a useful yardstick for building designers concerned with energy conservation.

The annual energy budget design levels based on the U.S. proposal, when applied to Toronto are:



ENERGY BUDGET DESIGN LEVELS / YEAR

	Clinic	Community Centre	Gymnasium	Hospital	Hotel/Motel	Multi-Family High-Rise	Multi-Family Low-Rise	Nursing Home	Office, Large	Office, Small	School, Elementary	School, Secondary	Shopping Centre	Store	Theatre/Auditorium	Warehouse	Single-Family	Semi-Detached
mj/m²	580	465	587	1520	756	569	468	734	511	479	562	832	644	637	637	360	670	832
mbtu/ft²	53	41	54	140	68	52	42	66	46	43	43	51	75	58	58	31	61	51
kwh/m²	161	129	163	422	210	158	130	204	142	133	133	160	231	179	177	100	192	160
kwh/ft²	17.3	13.9	17.5	45.4	22.6	17.0	14.0	22.0	15.3	14.3	14.3	16.8	24.9	19.3	19.3	10.7	20	16.8

Toronto Sun Chart *(Latitude: 43 degrees, 40 minutes, North)*

EST - Eastern Standard Time (Bold Face under 'Time') to be used for March 21 and December 21.

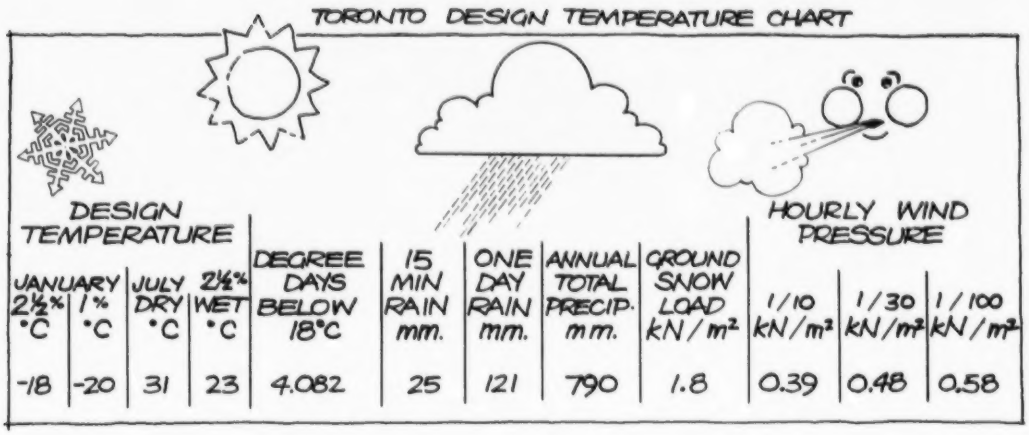
DST - Daylight Saving Time, to be used for June 21 and September 21.

Alt. - The Altitude is the angle, expressed in degress, measured vertically, between the sun and the horizontal plane of the horizon.

Az. - The azimuth is the angle, expressed in degrees, measured horizontally from the North meridian. For morning hours it is measured in an easterly direction; for afternoon hours, westerly.

5.30 Shadow Length Multiplier. Multiply height by 5.30 for shadow length.

Time	March 21		June 21		Sept 21		Dec. 21	
	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	A
4:18 a.m./ 8:18 p.m.			Sunrise - 5:35 DST					
5:18 a.m./ 9:18 p.m.			Sunset- 9:04 DST					
5:18 a.m./ 7:18 p.m.			6.1	117.0				
6:18 a.m./ 8:18 p.m.			(9.37)					
6:18 a.m./ 6:18 p.m.	Sunrise- 6:20 EST		16.0	107.3	Sunrise- 7:20 DST			
7:18 a.m./ 7:18 p.m.	Sunset- 6:31 EST		(3.48)		Sunset- 7:31 DST			
7:18 a.m./ 5:18 p.m.	10.7	79.5	26.6	97.8	10.7	79.5	Sunrise- 7:50 EST	
8:18 a.m./ 6:18 p.m.	(5.30)		(2.00)		(5.30)		Sunset- 4:42 EST	
8:18 a.m./ 4:18 p.m.	21.2	68.1	37.3	87.7	21.1	68.1	3.1	52.7
9:18 a.m./ 5:18 p.m.	(2.59)		(1.31)		(2.59)		(18.5)	
9:18 a.m./ 3:18 p.m.	30.6	55.2	48.0	75.8	30.6	55.2	11.0	41.4
10:18 a.m./ 4:18 p.m.	(1.69)		(.900)		(1.69)		(5.14)	
10:18 a.m./ 2:18 p.m.	38.5	39.7	58.0	59.9	38.5	39.7	17.2	28.7
11:18 a.m./ 3:18 p.m.	(1.25)		(.624)		(1.25)		(3.23)	
11:18 a.m./ 1:18 p.m.	44.0	21.1	66.0	35.8	44.0	21.1	21.2	14.8
12:18 p.m./ 2:18 p.m.	(1.03)		(.445)		(1.03)		(2.58)	
12:18 p.m.	46.0	0	69.4	0	46.0	0	22.6	0
1:18 p.m.	(0.96)		(.375)		(0.96)		(2.40)	



DESIGN TEMPERATURE									HOURLY WIND PRESSURE		
JANUARY 2½% °C	JANUARY 1% °C	JULY DRY °C	JULY 2½% WET °C	DEGREE DAYS BELOW 18°C	15 MIN RAIN mm.	ONE DAY RAIN mm.	ANNUAL TOTAL PRECIP. mm.	GROUND SNOW LOAD kN/m²	1/10 kN/m²	1/30 kN/m²	1/100 kN/m²
-18	-20	31	23	4.082	25	121	790	1.8	0.39	0.48	0.58

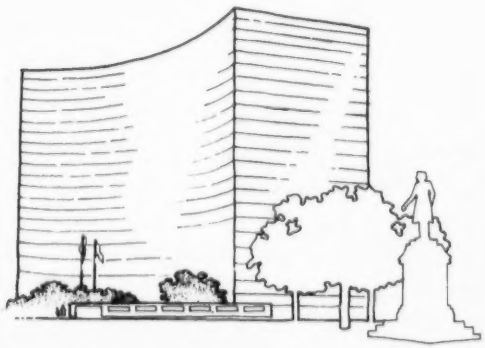
For offices, an occupancy period of 2,520 hours should be assumed (10 hours per day for five days per week, less holidays).

For residential buildings, heating season is from September 15 to June 1, with a provision for a heating level of 21 degrees Celsius (70 degrees Fahrenheit).

The Building Research Division of the National Research Council of Canada has published some standard components for energy consumption of schools and office buildings. If similar "performance indicators" could be established for large-scale structures, based on the experience of Toronto developers, it would provide a valuable data base for architects and planners. This information could be used to evaluate the energy consumption of existing buildings, or assist in creating energy-efficient designs for new structures. An equally important benefit could result if this information is used to raise the energy consciousness of building occupants, property managers and civic officials.

A comparison of existing office buildings in Toronto reveals a wide disparity in energy consumption levels, ranging from less than 150 kwh/m² = 540 mj/m² (14 kwh/sq. ft.) in Hydro Place, to over 536 kwh/m² = 1930 mj/m² (50 kwh/sq. ft.) in City Hall. In general, buildings constructed in Toronto before the 1973 "Energy Crisis" have substantially higher energy consumption levels.

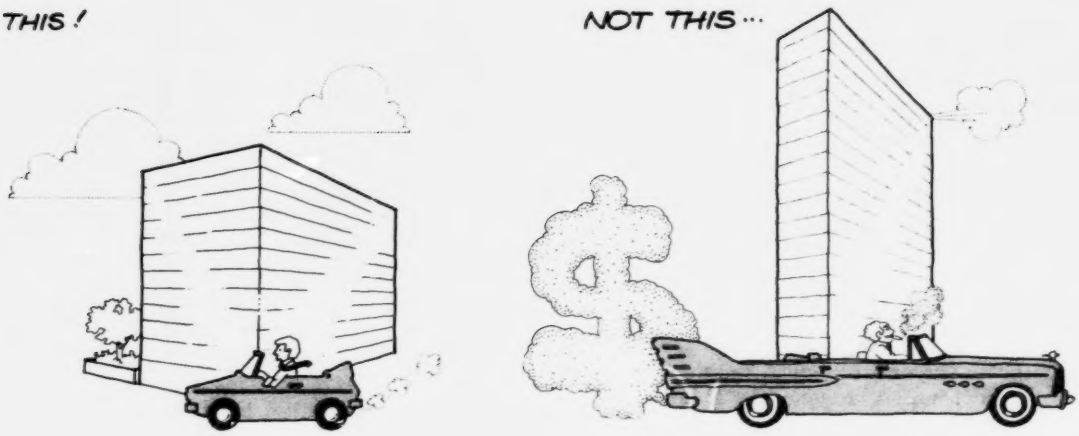
Despite differences in equipment used and hours of operation, comparisons are valid. For most office, apartment or mixed-use buildings in Toronto, a figure of 18 kwh/sq. ft. anually or 700 mj/sq. m should be used as a reference point when evaluating energy consumption. Buildings which now use or are projected to consume less than this amount can be considered energy efficient. The rest, unless they have special needs which require higher levels of energy consumption, could be improved.



ONTARIO HYDRO BUILDING
150 kwh/m²

CITY HALL
536 kwh/m²

Acknowledgements



These guidelines have been prepared by the Zoning and Official Plan Division of the City of Toronto Planning and Development Department in co-operation with the Information and Communication Services Division of the City Clerk's Department.

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Much of the information included in this publication is based upon an analysis of existing and proposed large-scale buildings in downtown Toronto. Numerous energy/architectural publications, handbooks and textbooks were also referred to, as indicated in the list of references.

Space limitations do not permit naming those professionals, business and government officials whose expertise, guidance and support was instrumental in the creation of this document. Hopefully they will feel justly rewarded for their input if these guidelines contribute to the understanding and application of energy-conscious design in large-scale buildings.

For further information contact:

City of Toronto
Planning and Development Department
20th Floor, East Tower
City Hall
Toronto
M5H 2N2

Telephone: 416/947-7187

Prepared by
Alex Telegdi
City of Toronto
Planning and Development Department
Zoning and Official Plan Division
September, 1983

Illustrations
by Gram Campbell

Energy Terminology Explained

This glossary includes terms used in this booklet as well as terminology frequently used in energy analysis work.

ASHRAE
American Society of Heating, Refrigerating and Air Conditioning Engineers

ASHRAE Standard 90-75
Energy Conservation "component performance" standards for new building design developed and adopted by ASHRAE in 1975.

Capacity, Thermal or Heat Storing
The property of a material which determines the amount of heat or cooling it will absorb. It is a function of the mass of the material and its specific heat.

Comfort Envelope
The area on a psychrometric chart enclosing all those conditions described in ASHRAE Standard 55-74 "Thermal Environmental Conditions for Human Occupancy", as being comfortable.

Comfort Zone (average)
The range of effective temperatures over which the majority (50 percent or more) of adults feels comfortable, (extreme) the range of effective temperatures over which one or more adults feel comfortable (see Effective Temperature).

Conduction
The method whereby heat is transferred from one body to another without physical displacement of the matter within the bodies.

Conductivity, Thermal
(k) The time rate of heat flow through a homogeneous material per unit area and thickness, under steady-state conditions, when a unit temperature gradient is maintained in the direction normal to the cross-sectional area.

Control, Automatic
A device used to regulate a system on the basis of the response to changes in the magnitude of some property of the system, e.g. pressure, temperature.

Consumption (energy)
The total amount of energy used over a specific period of time, usually a month or a year. In the past the common unit of energy consumption for buildings was the BTU (British Thermal Unit). Now it is the Joule. Each energy source has its own unit of consumption for billing, which can be converted to joules. For electricity it is the kilowatt-hour, for gas it is the cubic metre, and for most fuels it is the litre or kilogram.

Convection
The transfer of heat by movement of a fluid (gas, vapour or liquid).

Convection, Forced
Convection resulting from circulation of a fluid by a fan or pump.

Convection, Natural
Circulation of a gas, vapor or liquid medium (usually air or water) due to differences in density resulting from temperature changes.

Cooling Load
The rate at which heat must be removed by the cooling equipment to maintain indoor comfort conditions. (The cooling load differs from heat gain in that the radiant part does not immediately appear as the cooling load but is absorbed by surfaces that enclose the space. When these surfaces become warmer than the indoor air, heat is transferred to the air by convection.)

Degree Day, Heating
A unit measurement based on temperature difference and time, used in estimating average heating requirements of a building.

Dehumidification
The condensation of water vapor from air by cooling below the dewpoint or removal of water vapor from air by chemical or physical methods.

Demand
The rate at which energy or fuel is consumed by a piece of equipment, or by the building as a whole. Demand is most often measured for electricity and is usually expressed in kilowatts. Most electric companies base their demand charges on the highest amount of energy consumed per 15 or 30 minutes each month. This is an "integrated" demand. Some companies may use the highest instantaneous rate of energy consumption instead, or an instantaneous demand.

Demand Charge
A charge based on demand, included in utility bills.

Demand Limiting (load levelling)
An equipment control method which aims at reducing peak energy demands by turning equipment off usually to defer loads as a peak is approached, according to an established priority schedule. Manual Demand Limiting relies on building operators to predict peak periods based on operation records and experience. Automatic Demand Limiting Equipment monitors energy use and shuts equipment down as a peak is approached.

Demand Meter
A meter which measures demand. Usually a recording electric meter which records the maximum demand for a period of time (usually one-quarter or one-half hours) and then resets to 0.

Design Outside Temperature
The outdoor temperature used in the calculation of the heating load. This temperature is derived by statistical methods and is not necessarily the lowest temperature ever recorded for a given locality

Diurnal Temperature Range
The range of temperature occurring over a 24-hour time span.

Edge Loss
The heat loss where the exterior walls of a building meet the ground floor slab.

Effective Temperature
An arbitrary index which combines into a single value the effect of temperature, humidity and air movement on the sensation of warmth or cold felt by the human body.

Emissivity, Thermal
The capacity of a material to emit radiant energy. Emittance is the ratio of the total radiant energy emitted by a body to that emitted by a "black body", (a perfect absorber of radiant heat that emits none) at the same temperature.

Energy
The capacity for doing work. Different forms may be transformed from one type into another, such as thermal (heat), mechanical (work), electrical, and chemical. Energy is measured conventionally in kilowatt-hours (KWH) or British Thermal Units (BTU). Energy is measured in SI units in joules (j) where 1 joule = 1 watt second.

Energy Analysis
A comprehensive study of a building's energy use and costs to determine how much, when, why, and where energy is used in the building. It will allow the energy planner to determine the feasibility of the opportunities identified by the energy audit as requiring further study and to identify and evaluate many new opportunities as well. It may also be used to determine energy code compliance since it includes a mathematical simulation of the building's energy use.

Energy Audit
A specific accounting of the various forms of energy used during a designated period of time, usually annually. It aims at identifying the major opportunities for improving a building's energy performance through a short study of the building; its operation and use; its equipment; and its energy bills.

Energy Budget
A design or consumption budget for a building or space use which is expressed in energy units that reflect the energy used to operate the various service systems.

Energy Management System
An automatic building control system which may include demand limiting, duty cycling, equipment startup and shutdown, and building monitoring, and utilizes a strategy designed to maximize energy efficiency and minimize energy costs.

Exfiltration
Indoor air leakage to the exterior through building envelope caused by a pressure differential.

HVAC
Heating, ventilating, and air conditioning

HVAC System
A system that provides heating, ventilating, and/or air conditioning within or associated with a building.

Heat Exchanger
A device used to transfer heat from a fluid flowing on one side of a barrier to a fluid flowing on the other side of the barrier. Quite often this is done by running a coil of pipe through a tank.

Heat Gain
As applied to HVAC calculations, it is that amount of heat gained by a space from all sources, including people, lights, machines, sunshine, etc. The total heat gain represents the amount of heat sensible and latent, that must be removed from a space to maintain desired indoor conditions. (See Cooling Load.)

Heat Loss
The sum cooling effect of the building structure when the outdoor temperature is lower than the desired indoor temperature. It represents the amount of heat that must be provided to a space to maintain indoor comfort conditions.

Heat Pump
A refrigeration system designed so that the heat extracted at a low temperature and the heat rejected at a higher temperature may be used alternately for heating and cooling functions respectively.

Heat Recovery
Heat utilized which would otherwise be wasted.

Heat Sink
A body (water, earth, metal, etc.) capable of accepting and storing heat. It can also serve as a heat source.

Heating Load
The rate at which heat must be provided by the heating equipment to maintain indoor comfort conditions. This is seldom the same as the heat loss, since the building may have internal sources of heat gain which counteract some of the heat loss.

Infiltration
Outdoor air leakage into a building. It most often occurs at cracks around doors, windows and other openings and is caused by the pressure effects of wind and the effect of differences in the indoor and outdoor air density.

Isolation
The solar radiation incident at the earth's surface.

Insulation
A material having a relatively high resistance to heat flow and used principally to retard the flow of heat. Four major classifications of building insulating materials are: 1) batt, 2) loose fill, 3) reflective, and 4) rigid.

Integrated Demand
The total energy consumed in a time period divided by the time expressed in hours. Note that this can be considerably different than instantaneous demand. Usually a one-half hour period is used.

Kilowatt (kw)
A unit of power equal to 1,000 watts, or to energy consumption at a rate of 1,000 joules per second. It is usually used for electrical power.

Latent Heat
The change in heat quantity that occurs without any corresponding change in temperature. Usually accompanied by a change of state; for example, water may change to steam, or the moisture content in air may be increased.

Life-Cycle Cost Analysis
The process of accounting for the capital and operational costs over the useful life of a building.

Megajoule
Unit of power equal to 0.277 kilowatt hour or 1,000 joules.

Megawatt
Unit of power equal to 1,000 kilowatts or 1 million watts.

Microclimate
Climate at specific site as defined by local variations in the regional climate caused by topography,

vegetation, soils, water conditions, as well as man-made construction.

Multi-Zone System
A HVAC control air-handling unit that provides hot and cold air and facilities for mixing these at the unit to give different supply temperatures to a number of zones.

Night Set-Back
A HVAC control strategy which maintains lower room temperatures during unoccupied periods in the heating season.

Non-Renewable Energy
A depleting energy source which is virtually impossible to recreate, such as the fossil fuels (oil, coal, natural gas).

"Off-Peak" Generation
The practice of generating hot or cold water in a building during the hours when utility rates are lowest and storing it for later use. Especially advantageous when demand charges are high or when "time-of-day" rates are employed.

Passive Design Methods
Using building elements to accept, store, and distribute the flows of energy from nature (most often solar) to provide benefits to activities and processes within the building without the use of external power. If external power is required for distribution by fans or pumps it is called a "hybrid" system.

Payback Period
The amount of time it takes the savings resulting from a modification to "pay back" the costs involved. A "simple" payback period does not consider the time value of money. A discounted payback period does.

Performance Standards
Standards describing performance in terms of minimum energy required of entire buildings and their energy using systems based on weather conditions, occupancy patterns, type of energy source and other pertinent energy use factors.

Prescriptive Standards
Design standards stipulating procedures in terms of specific materials and components rather than building performance.

R-Value
Thermal resistance, insulation value in Imperial System. Metric (SI) equivalent is RSI.

Radiation
Energy, in the form of electromagnetic waves, which is continually passing between the surfaces of all bodies.

Recovered Energy
Energy utilized which would otherwise be wasted.

Renewable Energy
Sources of energy derived from incoming solar radiation (including photosynthetic processes) from phenomena resulting therefrom (including wind, waves and tides, lake or pond thermal differences) and energy derived from the internal heat of the earth (including nocturnal thermal exchanges). (Synonyms include non-depletable, current income energy, regenerative energy.)

SI Units
International system of units (metric) from the French "Le System International d'units".

Steady State
Refers to steady state temperature conditions which are often assumed when estimating heat flow through the building envelope. This ignores the effects of changing outdoor temperatures and thermal capacity. It is generally regarded as an accurate assumption when average loads are being calculated particularly if the temperature difference between indoor and outdoor air is great with respect to the short-term changes in the outdoor air temperature or if the heat storing capacity of the building is small with respect to the total heat flow as is the case when lightweight building materials are used. It is not considered accurate for determining peak loads especially in buildings with high heat storing capacity or in climates with large daily variations in outdoor air temperature and solar radiation.

Thermal Zone
One or more spaces within a building that have similar cooling and heating load patterns and can therefore have common HVAC system controls.

"Time-of-day" Rates
Rate structures used by utility companies which charge higher rates during the high use periods of the day to discourage energy use during high use hours, reduce peak generating demands, and encourage more even and efficient use of electricity generating plants.

Transmissivity
The capacity of a material to transmit radiant energy.

U-Value
The heat flow rate through a given construction assembly, air to air, expressed in BTU/Hr./Sq.Ft./ degree difference between indoor and outdoor temperatures. The coefficient of heat transmission for a construction assembly.

Vapor Barrier
Any thin, waterproof membrane used to substantially reduce passage of moisture, such as under concrete slabs, in wall assemblies or roofs.

Variable Volume System
A HVAC system that operates at a constant temperature and varies the volume of air supplied to any space in accordance with its cooling requirements.

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